RECENT RESULTS ON $\psi(2S)$ DECAYS AT BES

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Recent results on $\psi(2S)$ decays, including 10 Vector + Pseudoscalar (VP) modes and $p\bar{p}\pi^0(\eta)$, are reported with 14×10^6 $\psi(2S)$ events collected with the BESII detector. Cross sections and form factors for $e^+e^- \to \omega\pi^0$, $\rho\eta$, and $\rho\eta'$ at the center of mass energies of 3.650, 3.686, and 3.773 GeV are measured simultaneously.

1 Introduction

A strong violation to the "12% rule" predicted by perturbative QCD was first observed by the MarkII experiment in the Vector-Pseudoscalar (VP) meson final states, $\rho\pi$ and $K^{*+}(892)K^- + c.c.$ [1]. Significant suppressions observed in four Vector-Tensor decay modes [2] make the puzzle even more mysterious. Numerous theoretical explanations have been suggested [3], but the puzzle still remains one of the most intriguing questions in charmonium physics.

The study on $\psi(2S) \to p\bar{p}\pi^0(\eta)$ provides a chance to study the N^* resonances, which play important roles on our understanding of the nonperturbative QCD.

2 Analysis of $\psi(2S) \to \pi^+\pi^-\pi^0$

The selected $\pi^+\pi^-\pi^0$ events are fitted in the helicity amplitude formalism with an unbinned maximum likelihood method using MINUIT [4]. The fit shown in Fig. 1 describes the data reasonably well, and the $\rho(2150)$ serves as an effective description of the high mass enhancement near 2.15 GeV/c^2 in $\pi\pi$ mass [5]. The branching fractions of $\psi(2S) \to \pi^+\pi^-\pi^0$, $\rho(770)\pi$ and $\rho(2150)\pi \to \pi^+\pi^-\pi^0$ are $(18.1 \pm 1.8 \pm 1.9) \times 10^{-5}$, $(5.1 \pm 0.7 \pm 1.1) \times 10^{-5}$ and $(19.4 \pm 2.5^{+11.5}_{-3.4}) \times 10^{-5}$, respectively, where the first error is statistical and the second one is systematic.

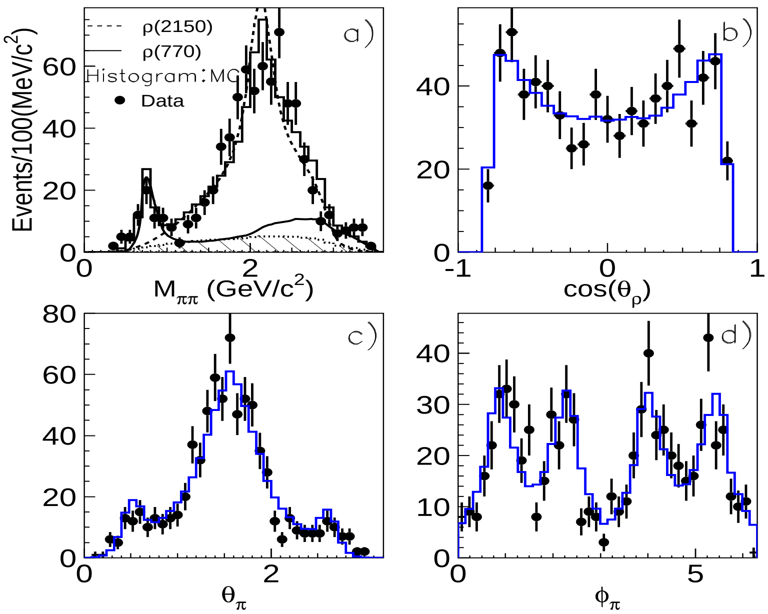

Figure 1: Comparison between data (dots with error bars) and the final fit (solid histograms) for (a) two pion invariant mass, with a solid line for the $\rho(770)\pi$, a dashed line for the $\rho(2150)\pi$, and a hatched histogram for background; (b) the ρ polar angle in the $\psi(2S)$ rest frame; and (c) and (d) for the polar and azimuthal angles of the designated π in ρ helicity frame.

3 Analysis of Electromagnetic Decays $\psi(2S) \to \omega\pi, \rho\eta$ and $\rho\eta'$

For this analysis, beside the $\psi(2S)$ data sample, we also analyze 6.42 pb^{-1} of continuum data at $\sqrt{s} = 3.650$ GeV [6], and 17.3 pb^{-1} at the $\psi(3770)$ [7]. Table 1 lists the cross sections of $e^+e^- \to \omega\pi, \rho\eta$ and $\rho\eta'$ and the corresponding form factors; the branching fractions of $\psi(2S) \to \omega\pi, \rho\eta$ and $\rho\eta'$ are listed in Table 2 [8].

Table 1: Cross sections and form factors measured for $e^+e^- \to \omega\pi^0$, $\rho\eta$, and $\rho\eta'$ at $\sqrt{s} = 3.650$, 3.686, and 3.773 GeV.

Channel	Samples	$\mathcal{L}$ (pb^{-1})	$N^{obs}_{Cont.}$	ϵ (%)	$1+\delta$	σ_0 (pb)	$\lvert\mathcal{F}_{VP}\rvert$(GeV^{-1})
	3.650 GeV	6.42	$7.3^{+3.3}_{-2.7}$	5.09	1.032	$24.3^{+11.0}_{-9.0} \pm 4.3$	$0.051^{+0.12}_{-0.10}$
$\omega\pi^0$	3.686 GeV	19.72	$17.3^{+5.7}_{-5.1}$	4.98	1.031	$19.2^{+6.3}_{-5.7} \pm 2.9$	$0.045^{+0.008}_{-0.007}$
	3.773 GeV	17.3	$8.6^{+4.0}_{-3.3}$	5.09	1.028	$10.7^{+5.0}_{-4.1} \pm 1.7$	$0.034^{+0.008}_{-0.007}$
	3.650 GeV	6.42	$2.3^{+2.1}_{-1.4}$	10.9	1.028	$8.1^{+7.4}_{-4.9} \pm 1.1$	$0.030^{+0.014}_{-0.009}$
$\rho\eta$	3.686 GeV	19.72	$16.0^{+5.6}_{-5.0}$	10.9	1.028	$18.4^{+8.6}_{-7.8} \pm 1.9$	$0.046^{+0.011}_{-0.010}$
	3.773 GeV	17.3	$5.8^{+3.3}_{-2.6}$	10.7	1.026	$7.8^{+4.4}_{-3.5} \pm 0.08$	$0.030^{+0.009}_{-0.007}$
	3.650 GeV	6.42	< 4.4	4.33	1.021	< 89	< 0.192
$\rho\eta'$	3.686 GeV	19.72	$2.9^{+2.4}_{-1.6}$	4.43	1.020	$18.6^{+15.4}_{-10.3} \pm 3.6$	$0.050^{+0.021}_{-0.015}$
	3.773 GeV	17.3	< 3.9	4.56	1.019	< 28	< 0.106

Fig. 2 shows the results of the form factor $|\mathcal{F}_{\omega\pi^0}|$ from our measurements, CMD-2 [9], and DM2 [10], and the calculated value of $|\mathcal{F}_{\omega\pi^0}|$ at $s = m^2_{J/\psi}$. Curve (A) is predicted by J.-M. Gérard and G. López Castro [11] as:

$$|\mathcal{F}_{\omega\pi^0}(s \to \infty)| = \frac{f_\omega f_\pi}{3\sqrt{2}s}, \tag{1}$$

with $f_\omega = 17.05 \pm 0.28$ and $f_\pi = 0.1307$ GeV, the decay constants of ω and π, respectively.

Curve (B) is predicted by Victor Chernyak [12]:

$$|\mathcal{F}_{\omega\pi^0}(s)| = |\mathcal{F}_{\omega\pi^0}(0)| \frac{m_\rho^2 M_{\rho'}^2}{(m_\rho^2 - s)(M_{\rho'}^2 - s)}, \tag{2}$$

where m_ρ and $M_{\rho'}$ are the masses of $\rho(770)$ and $\rho(1450)$, respectively. From Fig. 2, our results agree with the description of Eq. (1).

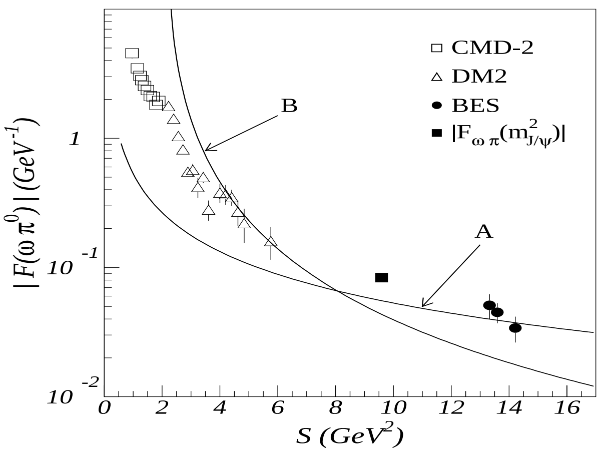

Figure 2: Energy dependence of the $e^+e^- \to \gamma^* \to \omega\pi^0$ form factor. Curve (A) is calculated with Eq. (1), while curve (B) is calculated with Eq. (2).

4 Measurements of $\psi(2S)$ decays into $K^*(892)\bar{K} + c.c.$, $\phi\pi^0$, $\phi\eta$, $\phi\eta'$, $\omega\eta$, and $\omega\eta'$

For $\psi(2S) \to K^*(892)\bar{K} + c.c.$, we study its final state $K_s^0 K^\pm \pi^\mp \to \pi^+\pi^- K^\pm \pi^\mp$ [13]. The other decay modes are studied with ϕ decays to K^+K^-, ω to $\pi^+\pi^-\pi^0$, η' to $\eta\pi^+\pi^-$ or $\gamma\pi^+\pi^-$, and π^0 and η to 2γ [14]. The results are listed in Table 2.

Table 2: Branching fractions and upper limits (90% C.L.) measured for $\psi(2S)$ decays. Results for corresponding J/ψ branching fractions and the ratios $Q_h = \frac{B(\psi(2S)\to h)}{B(J/\psi\to h)}$ are also given.

h	$B(\psi(2S)\to) \times 10^{-5}$	$B(J/\psi \to) \times 10^{-4}$	Q_h (%)
$\rho\pi$	$5.1 \pm 0.7 \pm 1.1$	127±9	0.40 ± 0.11
$K^*(892)^+K^- + c.c.$	$2.9^{+1.3}_{-1.7} \pm 0.4$	50±4	$0.59^{+0.27}_{-0.36}$
$K^*(892)^0\bar{K}^0 + c.c.$	$13.3^{+2.4}_{-2.8} \pm 1.7$	42±4	3.2 ± 0.8
$\omega\pi^0$	$1.87^{+0.68}_{-0.62} \pm 0.28$	4.2±0.6	$4.4^{+1.8}_{-1.6}$
$\rho\eta$	$1.78^{+0.67}_{-0.62} \pm 0.17$	1.93±0.23	$9.2^{+3.6}_{-3.3}$
$\rho\eta'$	$1.87^{+1.64}_{-1.11} \pm 0.33$	1.05±0.18	$17.8^{+15.9}_{-11.1}$
$\phi\pi^0$	< 0.41	< 0.068	–
$\phi\eta$	$3.3 \pm 1.1 \pm 0.5$	6.5±0.7	5.1 ± 1.9
$\phi\eta'$	$2.8 \pm 1.5 \pm 0.6$	3.3±0.4	8.5 ± 5.0
$\omega\eta$	< 3.2	15.8±1.6	< 2.0
$\omega\eta'$	$3.1^{+2.4}_{-2.0} \pm 0.7$	1.67±0.25	19^{+15}_{-13}
$p\bar{p}\pi^0$	$13.2 \pm 1.0 \pm 1.5$	10.9±0.09	12.1 ± 1.9
$p\bar{p}\eta$	$5.8 \pm 1.1 \pm 0.7$	2.09±0.18	2.8 ± 0.7

5 Analysis of $\psi(2S) \to p\bar{p}\pi^0(\eta)$

The final states of these two decay modes are the same $p\bar{p}\gamma\gamma$, and the signal event numbers are got by fitting the $\gamma\gamma$ invariant mass distribution in the selected events with $p\bar{p}\gamma\gamma$ final state [15]. The branching fractions for $\psi(2S) \to p\bar{p}\pi^0$ and $\psi(2S) \to p\bar{p}\eta$ are listed in Table 2. For $\psi(2S) \to p\bar{p}\pi^0$, the errors are much smaller than the previous measurement by Mark-II [1]. There are enhancements with $p\pi$ and $p\eta$ mass around 1.5 GeV, and weak evidences for the $p\bar{p}$ threshold enhancements in both channels.

6 Summary

We report the results on $\psi(2S)$ decays into 10 VP channels and $p\bar{p}\pi^0(\eta)$ final states. The branching fractions in our measurement are consistent with those of CLEO [16]. With the measured branching fractions, the "12% rule" is tested. From the ratios Q_h in Table 2, we see the channels of $\rho\eta$, $\rho\eta'$, $\phi\eta'$, $\omega\eta'$ and $p\bar{p}\pi^0$ are consistent with "12% rule", while the others are suppressed. The solution to the "$\rho\pi$ puzzle" seems to need more accurate measurements and further effort from theory.

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